PROJECT AUTHORIZATION NO. HWY-2004-14

under

MASTER AGREEMENT FOR RESEARCH AND TRAINING SERVICES BETWEEN THE NORTH CAROLINA DEPARTMENT OF TRANSPORTATION AND
NORTH CAROLINA STATE UNIVERSITY ON BEHALF OF
THE INSTITUTE FOR TRANSPORTATION RESEARCH AND EDUCATION
(Contract No. 98-1783)

Project Title: Developing a Simplified Method for Predicting Deflection in Steel Plate Girders Under Non-Composite Dead Load for Stage-Constructed Bridges

Formal Statement of Work: See attached proposal

Period of Performance: July 1, 2003 – June 30, 2005

Budget Authorization: First year: $87,871 Second year: $61,129 Total: $149,000

Property to be Furnished by the Department: None

Key Personnel: Emmett Sumner, Sami Rizkalla

Project Monitor: Shannon Lasater

Additional Terms and Conditions: Research Project Guidelines as posted on ITRE's website at *http://itre.ncsu.edu/research/ongoingguidelines.htm.*

IN WITNESS WHEREOF, the parties hereto have executed this Project Authorization as of

April 11, 2003.

NORTH CAROLINA STATE UNIVERSITY	NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
BY:_____________________________ Principal Investigators	BY:_____________________________
BY:_____________________________ N. C. State University	
BY:_____________________________ Director of ITRE	

FY 2004
NCDOT

Research Proposal

Amount of Funds Requested:	$149,000
Project Title:	**Developing a Simplified Method for Predicting Deflection in Steel Plate Girders Under Non-composite Dead Load for Stage-constructed Bridges**
Purpose of Proposal:	See attached summary
Organization:	North Carolina State University
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Major Subdivision Conducting Work:	Department of Civil Engineering
Principle Investigators:	Emmett Sumner Sami Rizkalla
Date:	April 11, 2003

EXECUTIVE SUMMARY

This proposal was developed in response to *Research Idea ST-04* in the NCDOT FY-2004 *Call for New Research Idea* (proposed by Mr. Tom Koch, Project Engineer in the Structure Design Unit). Many of today's bridge construction projects are erected in stages to limit traffic interruptions or to minimize the environmental impacts. Typically, one half of the bridge superstructure is constructed in the first stage and the other half constructed in the second stage. The final stage is to cast a closure strip to join the deck slabs of the two structures together.

Matching the final deck elevations of the first two stages of construction has created numerous problems during construction. Most common are construction delays caused by the need to reanalyze the structure and reset the screed and buildup elevations. Improperly aligned deck elevations between the two stages may require the need for grinding of the deck surface, after placing the closure pour. In addition, reduction of the thickness of the deck may result in reduction of the concrete cover leading to possible deterioration of the bridge deck. The misalignment of the two deck slab surfaces may occur due to differential non-composite deflections of the adjacent girders in different stages of construction.

Deflection calculations are normally based on a single girder line with no accommodation for the varying transverse distribution of the loads. The variation in the transverse load distribution occurs because of frame action exhibited by the cross-frames connecting the girder lines, the effects of bridge skew, and variations in non-composite dead load due to different overhang conditions.

The solution to this problem is to create a three-dimensional finite element computer model that is more accurately representative of the three-dimensional behavior of the structure. Creation of the computer models is a very time consuming task that must be performed by an engineer with considerable experience in computer modeling. This represents an extremely laborious task for the NCDOT to perform on the staged-construction projects.

The primary objective of this research is to develop an empirically based method to predict the non-composite deflection of steel plate girders in staged-constructed bridges. The effects of bridge skew, girder length, girder spacing, cross-frame stiffness, in-place deck slab thickness, and composite action on a portion of the girder length will be included in the method. Simple span, two continuous span, and three continuous span bridge configurations will be considered. The empirically based method will utilize a series of simple modifiers to adjust the traditionally predicted single girder line deflection to the expected staged-construction deflection. The formulation of the simplified method will require a combination of field measured data and extensive three-dimensional analytical simulation.

The proposed research will provide a direct benefit in cost savings to the NCDOT both in long-term and short-term. These benefits will realized by decreasing construction delays and design time required to predict the deflection during staged construction of the girders. In addition, the possible deterioration of the bridge deck and the needs for repairs due to insufficient concrete cover of the reinforcement will be eliminated.

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RESEARCH PLAN

Introduction

This proposal was developed in response to *Research Idea ST-04* in the NCDOT FY-2004 *Call for New Research Idea*. The research idea was proposed by Mr. Tom Koch, Project Engineer in the Structure Design Unit. The research team submitted a pre-proposal for this project on October 11, 2002. The Structures Research Subcommittee recommended the development of this full proposal, as stated in the November 26, 2002 letter of the State Research Engineer., Mr. Rodger Rochelle. The Subcommittee made the following recommendations, all of which have been incorporated into this proposal:

- A consideration of the actual in-place deck thickness should be noted in the analyses.

- The Guess Road structure over the Eno River (250 ft. HPS simple span) should be specifically mentioned as one structure from which to gather empirical data.

The research team met with Mr. Tom Koch and discussed some details of the NCDOT standard practices in staged constructed bridge projects. The results of these discussions have been incorporated into this proposal.

Problem Definition

Many of today's bridge construction projects are erected in stages to limit traffic interruptions or to minimize the environmental impacts. Typically in the first stage of construction, one-half of the girders will be placed and the bridge deck cast. The roadway traffic is then shifted onto the newly constructed bridge structure and the second stage of construction is begun. In the second stage the additional girders are placed and concrete deck elevations aligned with the previously cast deck in stage one. The final stage is to cast a closure strip to join the deck slabs from the two stages.

Matching the final deck elevations of the two stages has created numerous problems during construction. Construction delays have been caused by the need to reanalyze the structure and reset the screed and buildup elevations. Improperly aligned deck elevations between the two stages can create the need for grinding of the deck surface, after placing the closure strip. The misalignment of the two deck slab surfaces occurs because of differential non-composite deflections of the adjacent girders in different stages of construction (see Figure 1).

In cases where the final deck surface is acceptable, differential deflections of the girders can result in inadequate or excessive concrete cover for the reinforcing steel cover and possible thin bridge decks. Inadequate concrete cover and thin bridge decks often result in more rapid deck deterioration and an increased need for repairs.

Steel plate girders are cambered to account for the non-composite deflections caused by the weight of the concrete deck. As the deck concrete is placed, the girders deflect to their non-cambered position. The non-composite deflections, included in the camber, are calculated using a commercial software program such as Merlin-Dash. Typically, the deflection calculations are based on a single girder line with no consideration for the varying transverse distribution of the loads. The variation in the transverse load distribution occurs because of the frame action exhibited by the cross-frames between girder lines and the effects of bridge skew on the transverse load distribution behavior of the deck. In addition, the variations in non-composite dead load due to different overhang conditions and variations in the in-place deck slab thickness created by the construction staging are not considered in the conventional analysis. This results in the predicted non-composite bridge girder deflections that do not correlate well with the deflections observed during construction.

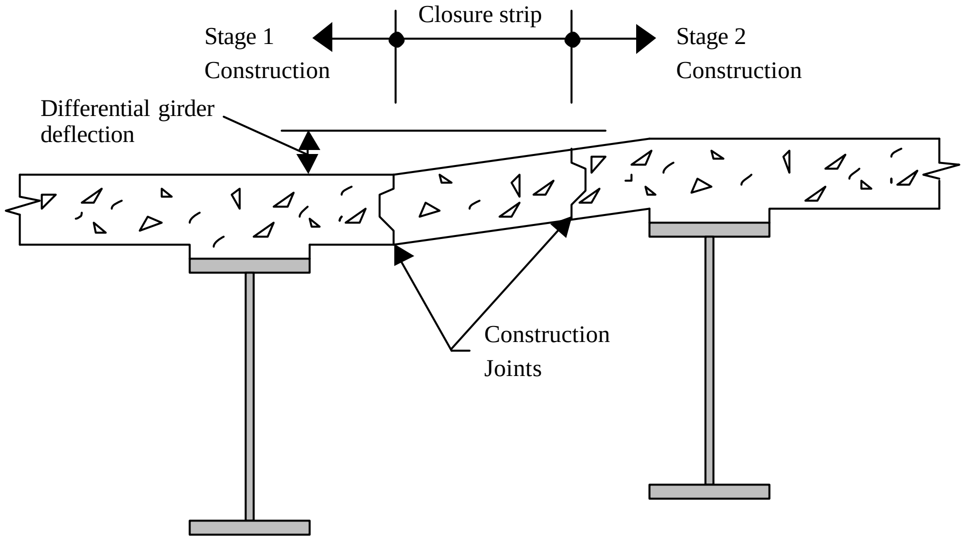

Figure 1: Misalignment of deck slab due to differential non-composite deflections

The solution to this problem is to create a three-dimensional finite element computer model that accurately represents the skewed geometry of the structure, frame action exhibited by the cross-frames, and the staged overhang conditions. Creation of the computer model is a very time consuming task that must be performed by an engineer with considerable experience in computer modeling. This represents an extremely laborious task for the NCDOT to perform on the staged-construction projects.

Research Objective

The primary research objective is to develop an empirically based method to predict the non-composite deflection of steel plate girders in staged-constructed bridges. The effects of bridge skew, girder length, girder spacing, cross-frame stiffness, in-place deck slab thickness, and composite action on a portion of the girder length will be included in the method. Simple span and two and three continuous span bridge configurations will be considered. The empirically based method will utilize a series of simple modifiers to adjust the traditionally predicted single girder line deflection to the expected staged-construction deflection. The formulation of the simplified method will require a combination of field measured data and extensive three-dimensional analytical simulation of the bridge structures.

Literature Review

Numerous studies on the behavior of composite steel plate girder bridges have been conducted. However, research on the behavior of steel girders under non-composite dead load is very limited. The majority of the relevant studies have focused on the transverse load distribution characteristics of skewed bridges after the bridge deck is cured.

Early studies by Newmark (1948), Ghali et. al. (1969) and Hilton (1971) investigated the differences in behavior of non-skewed and skewed bridges. More recent studies by Bishara et. al. (1993) and Miller et. al. (1992) included field studies that investigated the composite behavior of skewed bridges. Laboratory studies conducted by Helba et. al. (1994), Gupta and Kumar (1983) and Ebeido et. al. (1995, 1996) evaluated the load distribution characteristics and the ultimate strength of non-skewed and skewed steel girder bridge structures.

A number of studies have utilized finite element analysis to predict the behavior of steel girder bridges. Research by Tarhinik et. al. (1995) and Mabsout et. al. (1997) focused solely on finite element modeling. Other studies by Bishara et. al. (1993), Helba et. al. (1994), and Ebeido et. al. (1995, 1996) correlated finite element analysis results with field or laboratory measured data.

Overall Work Plan

The proposed research consists of literature review, analytical study, field measurement, and technology transfer, as follows:

- Literature review will focus on past studies on the behavior of skew bridge girders, related finite element modeling studies, and bridge construction monitoring projects. The review will include published reports by FHWA, NCHRP, and state DOT's, published articles in archival journals, conference proceedings, masters' theses, and doctoral dissertations. The information will be sought through library catalogs and online sources.

- The analytical study will consist of three-dimensional finite element modeling of the steel girder bridge structures using commercially available computer programs such as SAP 2000 or ANSYS. The finite element models will be used to conduct simulations of numerous different bridge structure configurations. Critical parameters such as span configuration, skew angle, girder spacing, girder span, number of girders, cross-frame stiffness, and deck slab thickness will varied to investigate their influence on the non-composite steel bridge girder deflections. Additional analytical study will be conducted to reduce the analytical and empirical field data and to develop the simplified method of predicting girder deflections.

- Field measurements will be made on several steel girder bridge projects to observe the behavior of the structures during placement of the deck slab. Measurements before and after deck placement will be taken to determine the non-composite girder deflections. The girder deflections will be measured along each girder at the quarter points of each span. Other points of measurement will be taken as deemed necessary by field conditions.

- Technology transfer will be primarily in the form of a comprehensive final report and will focus on disseminating the *products* of this research to the *customers* at NCDOT.

Details of the analytical study, field measurement, and technology transfer are presented in the subsequent sections.

Research Methodology and Itemized Tasks

To develop the simplified non-composite deflection prediction method, the following itemized tasks are proposed:

Task 1. Three-dimensional Finite Element Simulation

Three-dimensional finite element models of numerous steel plate girder bridge structures will be created using a commercially available computer programs such as SAP 2000 or ANSYS. Details of the cross-frames, connected between the girder lines, and the girder support conditions will be included to ensure accurate representation of the transverse load distribution. The initial models will be used to determine the optimum element type and level of mesh refinement. Additional finite element models will be utilized to conduct simulations of numerous bridge structure configurations. This approach facilitates the investigation of critical parameters such as span configuration, skew angle, girder spacing, girder span, number of girders, cross-frame stiffness, and deck slab thickness. Table 1 shows the range of parameters to be considered in this study. Consideration of different overhang conditions produced by the staged-construction sequence will be included in the analytical study. The effects of composite action along a portion of the girder length will also be included.

Table 1. Range of Critical Parameters

Critical Parameter	Range
Skew angle	0 to 75 degrees
Span configuration	Single span, Two span continuous, Three span continuous
Girder spacing	2 to 4 meters
Girder span	25 to 100 meters
Number of girders	4 to 12 girders
Deck slab thickness	230 millimeters

This analytical approach will result in the simulation of field conditions by the computer models. Each identified parameter will be varied to obtain an adequate amount of data to describe it's influence on the non-composite girder deflections. The exact number of models needed for each parameter will be dependant upon the variability of the parameter.

Task 2. Field Data Collection

The field measurement of steel girder non-composite deflections of bridges under construction will be performed. Single span, two continuous span, and three continuous span steel girder bridge structures will be measured. Measurements from a minimum of two bridge structures for each of the three span configurations will be necessary to obtain a correlation between the finite element simulation and the field deflection data. The number of bridges included in the field measurements will be dependant upon the availability of applicable projects under construction during the research project time. Clearly, the more field data that is gathered, the more accurate the simplified method will be.

The selection of the field measured bridge structures will be performed in collaboration with NCDOT personnel. It is anticipated that the selected bridge structures will be a combination of single and multiple stage constructed projects. Measurements from single stage-constructed structures will be used in conjunction with multiple stage-constructed projects to provide additional data. Preliminary discussions with NCDOT have identified four possible bridges that will be under construction in during the Fall of 2003. The four structures are as follows: Guess Road structure over the Eno River (76 meter HPS span), US 70 structure over Avondale Drive (34 meter span, 53 degree skew), US 70 structure over Duke Street (36 meter span, 111 degree skew), US 70 structure over Club Boulevard (32 meter span, 124 degree skew).

The field deflection measurements will be recorded at the quarter points along each span of the interior and exterior bridge girders as shown in Figure 2. The deflections will be determined by measuring the elevation of each point along the bridge girder before and after the bridge deck placed. The elevations will be measured using surveying techniques and laser technology. The particular surveying method and procedure utilized will be determined in collaboration with representatives from the NCDOT Locations and Surveying unit.

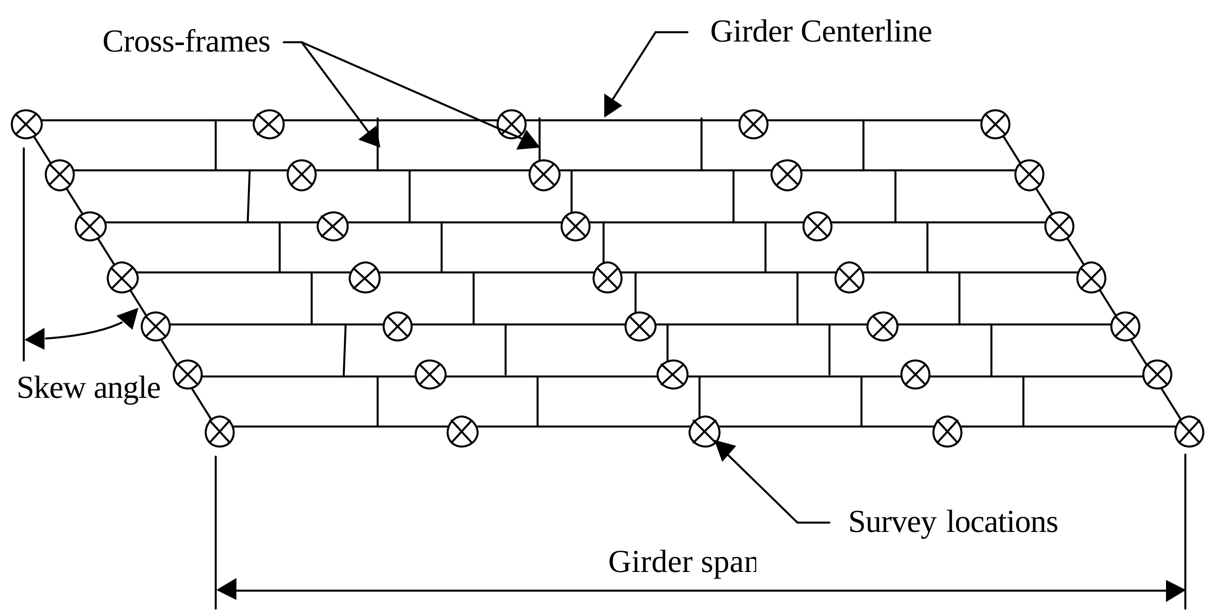

Figure 2. Deflection measurement locations

As allowed by the site conditions, additional deflection measurements may be recorded using string potentiometers and a computer controlled data acquisition system. The string potentiometers would be positioned on the ground below the bridge and connected to the bottom flange of the girder. These measurements would serve as verification points for the surveyed values.

Task 3. Correlation of Field Data

Three-dimensional finite element models will be created for each of the field measured bridges. Particular care will be taken to properly model the particular details of each structure. The deflection measurements obtained in the field will be compared to the deflections generated by the finite element model. The relationship between recorded field measurements and the deflections predicted by the finite element models will be investigated. As needed, the finite element model will be calibrated to match the field measured non-composite deflections. These calibrations will be used in the development of the simplified method.

Task 4. Development of Simplified Method

The field data, the results of the simulation, and single line girder analysis results will be used to generate the expected staged-construction deflection modification factors. The modification factors will be applied to the single girder line deflections, calculated by computer design programs such as Merlin-Dash.

Modification factors for the effects span configuration, skew angle, girder spacing, girder span, number of girders, cross-frame stiffness, and deck slab thickness will be generated. It is anticipated that the factors will be represented on a series of charts that can be quickly and easily interpreted by NCDOT engineers.

ANTICIPATED RESULTS AND SIGNIFICANCE

This research will develop a simplified method to predict the non-composite deflection of steel plate girders. The method will provide the NCDOT with a more efficient method to predict the differential girder deflections in stage-constructed bridges. The ability to accurately predict the deflections should circumvent many of the deflection related problems encountered during construction.

The Structure Design Unit of the NCDOT has identified the product from this research to be of immediate urgency. We concur with this assessment, and believe that this project can directly and immediately provide benefits in terms of construction cost savings to the NCDOT, both in long-term and short-term, as described below:

- Decrease construction delays and the costs associated with those delays.

- Decrease design time and effort previously used to create extensive computer models to predict staged-construction girder deflections.
- Decrease deck deterioration and repairs due to insufficient reinforcement cover and thin bridge decks.

IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

In this section, the main issues regarding implementation and technology transfer of the proposed research are discussed.

What is the primary "Product"?

The primary *product* of this research is the simplified procedure for predicting deflection in steel plate girders under non-composite dead load.

What are the secondary "Products"?

The secondary product of this research is the additional *knowledge* of the behavior of steel plate girders under non-composite dead load. There is very little research data available on the behavior of stage-constructed and skewed bridge structures. The field measurement combined with the finite element simulation will provide a much greater understanding the influence of the various parameters on the girder behavior.

Who within NCDOT will use the products? (Customers)

The customers of the above described products are the NCDOT structure design engineers.

Why should they use the products? (Market)

The structure design engineers can use the simplified prediction method to more accurately predict the non-composite girder deflections in stage-constructed bridge structures. Utilization of the method will avoid construction problems and additional costs caused by differential girder deflections.

How will they use such products?

The simplified method can be integrated directly into the design process used by structure design engineers.

What is needed for NCDOT customers to use products?

Once the research is complete, appropriate workshops could be used to inform all structure design engineers of the outcome of this research. Once the customers are equipped with the knowledge and guidelines for using the simplified method, they could easily incorporate the procedure into the steel girder design process.

The dissemination of the project findings is an integral part of this project. Information will be provided to the NCDOT through quarterly progress reports, as well as a comprehensive final report. The Research Team will work with the NCDOT personnel on developing the most effective means to transfer the knowledge gained in this project to appropriate personnel at the various divisions and districts within the NCDOT.

RESOURCES TO BE SUPPLIED BY NCDOT

The proposed research requires that the NCDOT provide access to appropriate bridge construction projects to allow for field deflection measurements. Personnel and surveying equipment from the Locations and Surveying unit is also required to assist in the measurement of the bridge girder elevations before and after placement of the concrete bridge deck. Design and construction details of the field measured structures will also be required.

EQUIPMENT AND FACILITIES

The Constructed Facilities Laboratory (CFL) is part of North Carolina State University's Engineering Graduate Research Center (EGRC). The CFL is a state of the art research laboratory with facilities for both experimental and analytical research. The CFL has three personal computer controlled data acquisition systems and numerous wire potentiometers that can be utilized to record the field data. In addition, high speed personal computers are accessible for generating the finite element models.

TIME REQUIREMENTS - SCHEDULE OF WORK

The proposed project will require two years to complete. The proposed timeline for the tasks in this project is shown in Table 2. The literature review, finite element simulation, and the field data collection will begin within the first quarter. The correlation of the field data will begin at the end of the first quarter and continue into the second year. The development of the simplified method will start at the beginning of the second year.

Table 2. Proposed Timeline

Task	**Year**	**First**				**Second**			
	Quarter	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Literature Review									

Finite element simulation								
Field Data Collection								
Correlation of field data								
Development of simplified method								
Preparation and review of final report								

QUALIFICATIONS AND ACCOMPLISHMENTS OF RESEARCHERS

The research team consists of two faculty members and two graduate students. Emmett Sumner is currently an instructor of structural engineering at the NC State University. He is a professional engineer with industry experience in bridge and transportation structure design. Sami Rizkalla is Distinguished Professor of Civil Engineering and Construction, Director of the Constructed Facilities Laboratory (CFL) at the NC State University, and Director of the NSF Industry/University Cooperative Research Center (RB^2C). It is anticipated that one graduate student will be a working towards a Ph.D. degree the other working toward a Master's degree.

OTHER COMMITMENTS OF RESEARCHERS

Emmett Sumner is currently involved in research with the NSF Industry/Government Collaborative Research Center on the use of FRP for "Repair of Bridges and Buildings with Composites", RB^2C. Sami Rizkalla is currently the director of the previously mentioned NSF Industry/Government Collaborative Research Center, and co-investigator in the research project funded by NCDOT and NSF in collaboration with Virginia Tech.

DIRECTLY RELATED PUBLICATIONS

AASHTO (2002). *Standard Specifications for Highway Bridges, Seventeenth Edition*, American Association of State Highway and Transportation Officials, Washington, D.C.

Bishara, A. G., Liu, M. C., and El-Ali, N. D. (1993). "Wheel Load Distribution on Simply Supported Skew I-Beam Composite Bridges," *Journal of Structural Engineering*, ASCE, Vol. 119, No. 2, pp. 399-419.

Ebeido, T. and Kennedy, J. B. (1995). "Shear Distribution in Simply Supported Skew Composite Bridges," *Canadian Journal of Civil Engineering*, Vol. 22, No. 5, pp. 1143-1154.

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Ghali, Strong and Bathe (1969). “Field Measurement of End Support Reactions of a Continuous Multi-Girder Skew Bridge,” *Second International Symposium on Concrete Bridge Design*, American Concrete Institute, SP-26, Chicago, ILL., pp 260-271.

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Miller, R. A., Aktan, A. E. and Shahrooz, B. M. (1992). “Destructive Testing of a Decommissioned Slab Bridge,” *Journal of Structural Engineering*, ASCE, Vol. 120, No. 7, pp. 2176-2198.

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Tarhinik, K. M., Mabsout, M., Harajli, M., and Tayar, C. (1995) “Finite Element Modeling Techniques of Steel Girder Bridges”, *Computing in Civil Engineering, Proceedings of the Second Congress held in conjunction with A/E/C Systems ’95 held in Atlanta, Georgia, June 5-8, 1995*, New York: ASCE, 0-7844-0088-1, 1995, pp. 773-780.